EOS LASER ATMOSPHERE WIND SOUNDER (LAWS) INVESTIGATION

Final Report
Under
Contract NAS5-30751

Covering the Period
1990-1994

Submitted by

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I. Review of Objectives

In January 1990, the PI was awarded a contract to perform a variety of tasks associated with his membership on the LAWS Science Team. Over the next five years, the contract underwent 9 modifications before terminating in December 1994 following the deselection of LAWS as an EOS-facility instrument. In this final report, the set of tasks that evolved are reviewed, the major accomplishments are summarized and a complete set of resulting references provided.

Initially, the effort was concentrated on the following core tasks:

1) preparation and attendance at LAWS Science Team meetings;
2) support of the EOS with science related activities; and
3) support LAWS and EOSDIS related work.

After the first year of effort, the tasks became further defined and included:

1) preparation of a plan for the LAWS Algorithm Development and Evaluation Laboratory (LADEL);

2) participation in the preparation of a joint CNES (French)/NASA proposal to build a space-based DWL;

3) involvement in the GLObal Backscatter Experiments (GLOBE);

4) evaluation of several DWL concepts including "Quick-LAWS", SPNDL and several direct detection technologies; and

5) an extensive series of system trade studies and Observing System Simulation Experiments (OSSEs).

In the following sections, some of the key accomplishments under this contract are briefly summarized with reference to interim reports, special reports, conference/workshop presentations and publications.

II. Major Accomplishments

1990

This first year of effort involved many organizational meetings and planning exercises. The Lidar Simulation Model (LSM) had been developed under a previous contract and was ready for use in exploratory system trade studies and for generating simulated DWL data sets for the OSSE groups (GSFC and FSU) to begin using. Some of the key accomplishments during 1990 were:

- Co-organized (with R. Atlas, GSFC) a LAWS workshop on OSSEs and other simulation studies supporting LAWS design and data assimilation. The workshop was held 27-28 March 1990 at GSFC.

- Conducted a series of LAWS performance trades involving scan angle, platform orbit and system baseline parameters (see 8 May 1990 Quarterly Report).

- Modified the LAWS Simulation Model to create simulated data bases suited to assimilation by GSFC and FSU global circulation models (see 17 July 1990 and 1 November 1990 Quarterly Reports).

- Provided simulated LAWS observations to GSFC (Atlas) and FSU (Krishnamurti) and contributed to two papers for presentation at the Annual AMS meeting in New Orleans, LA (see 1 November 1990 Quarterly Report).

The PI attended many planning meetings:

- EOSDIS Phase A review meeting, 12-16 February 1990, GSFC.

- GLOBE meeting, 7-8 March 1990, Huntsville, AL.

- EOSDIS Data Panel meeting, 21 March 1990, GSFC.

- EOSDIS prototyping planning meeting, 9-11 May 1990.

- ECMWF meeting to discuss future LAWS OSSEs, 3-5 September 1990, Reading, UK.

- IWG meeting at LaRC, 8 November 1990.

1991

A major effort went into developing a plan for a LAWS Algorithm Development and Evaluation Laboratory (LADEL) (see 11 March 1991 Contract Report). The primary purpose of such a facility was to satisfy the requirement that the LAWS Science Team deliver fully tested and portable algorithms to the EOSDIS for the production, archive and distribution of the instruments' data products. Considerable resources were used in setting up a plan that met all the program's needs.

In addition to the LADEL effort, the PI conducted or participated in the following LAWS related projects:

- 5 OSSEs using the GSFC GCM
- 3 OSSEs using the FSU Global Spectral Model
- Developed cloud, subgrid scale variance, and backscatter modules for the LAWS Simulation Model (LSM) (17 February 1992, Contractor Report)
- Performed Trade Studies involving (7 May 1991, Contract Report)

  - scan angle vs accuracies
  - laser energy vs prf
  - orbit coverage (e.g., 98° vs 55°)
  - wavelength (e.g., 2.1 vs 9.11 μm)

- Platform power budget studies (10 October 1991, Contract Report)
- Shot management to achieve science goals within laser lifetime constraints (31 July 1991, Contract Report)
- Comparative studies between "quad-beam" and "conical scan" instruments (conducted at LMD, Paris) (10 October 1991 Contract Report)

1992

The major areas of effort during 1992 were (1) OSSEs, (2) EOSDIS, (3) the LAWS power budget and (4) the planning for a joint USA/French mission.

1) OSSEs

There were three simulation initiatives:

a) the European Space Agency in co-operation with the French Meteorological Office, French LMD, British Meteorological Office and NASA.

b) NASA GSFC (Atlas) and SWA (Emmitt)

Following the LAWS Science Team meeting in January, a LAWS Simulation Committee met at GSFC and set the rules for a new series of LAWS OSSEs designed to address a number of critical issues and several criticisms of earlier experiments:

- improve global backscatter distribution by incorporating the GLOBE β profiles into a LOWTRAN based model;

- improve cloud coverage by switching to the Slingo (1987) cloud forecasts model;
- improve the parameterization of the subgrid scale variance; and
- run the OSSEs on the T106 Nature Run for both the baseline LAWS (20 joule) and the downsized LAWS (5 joule).

c) Florida State University (FSU) (Krishnamurti) and SWA (Emmitt)

FSU began preparation for single shot LOS data assimilations and ran a series of algorithm evaluation experiments.

2. EOSDIS

As a member of the EOSDIS Science Data Panel, the PI was involved in an ongoing effort to review and comment on plans and policy statements issued by the EOSDIS project office. In addition to the EOSDIS Panel activities, he also was selected to serve on the VØ Science Panel and to serve as Chairman of the HDAAWG which works with the MSFC DAAC personnel. While most of the EOSDIS related work was funded by the EOS project, it represented interface between LAWS, the instrument, and LAWS, the data generator.

3. Power Budget

As the LAWS program moved towards a joint mission with another partner(s), the issue of platform accommodation became an immediate issue. Furthermore, as the laser energy and optics were downsized to reduce risk and costs, the LAWS team had to evaluate means to optimize the use of limited platform power and limited shots.

4. Joint Mission Document

While no specific directives had been made to the LAWS Science Team (LST) to move forward with a joint US/French mission, several members of the LST collaborated with the French to assemble a mission science document. This document provided the science rationale for moving a joint mission to a new start status within both countries.

In addition to these major efforts, the PI was also involved in:

- preparing an article for the AMS Bulletin that described the LAWS program;
- providing simulated data sets to GSFC for input to 4 OSSEs;
- began an interaction with the FIRE program to establish a channel for communicating

common research results; and

- performing several LSM experiments in support of a proposed joint NASA/DOE DWL concept known as "Quick LAWS".

Additional details are reported in the 21 July 1992 and 2 March 1993 Contractor Reports.

1993

While the PI continued to participate in the OSSEs and in improving the performance of the LSM, the LAWS Science Team research began to shift towards using ground-based lidar systems to (1) evaluate several signal processing algorithms; (2) validate LSM SNR equations; and (3) simulate space-based sampling densities and perspectives (2 November 1993 Contractor Report).

Another major under taking in 1993 was the evaluation of a potential small satellite DWL proposed by the PI. SPNDL (Spinning Platform with a Non-Rotating Telescope Doppler Lidar) was reviewed by LaRC and was subjected to a series of end-to-end simulations. Scalability to a "full-up" LAWS was a major concern and it was decided that the concept was too radical and would only add to the complexity (and risk) of a first DWL mission.

Additional activities conducted under this contract in 1993 included:

- worked on BAMS article in preparation for draft submission to the LAWS Science Team in July;

- prepared and delivered a presentation to LaRC (contacts: Leo Station, R. Hess and L. McMaster) on the science goals of LAWS and some preliminary simulations comparing 2 μm and 9 μm sounders;

- continued evaluation of Quick-LAWS concepts as they evolved from a joint NASA/DOE study;

- attended the EOSDIS meetings (26-27 May) on behalf of the LAWS Science Team. Represented the type of queries and data processing requests that may be generated by researchers using the LAWS data products in combination with other sensor products (e.g., cloud cover, aerosol concentration, water vapor profiles, etc.);

- prepared and delivered a paper (Wood and Emmitt, 1993) to the AFGL Transmission Conference in Lexington, MA. The paper was meant to inform the atmospheric transmission scientific community of the needs and activities of the LAWS Science Team, in particular, the use of the AFGL's LOWTRAN in LAWS simulations.

The PI attended two meetings in the Washington, D.C. area: (1) the 2 μm review meeting where he also did a presentation; and (2) a meeting of at NASA Headquarters to discuss LAWS.

The PI traveled to the University of Michigan and met with Paul Hays and Webb Skinner regarding incoherent wind measurements for LAWS.

1994

In 1994, the likelihood that LAWS would be an EOS facility instrument became doubtful. However, the EOS project continued to fund work directly related to a DWL in space as well as a somewhat tangential effort involving the use of HDF to archive and distribute GLOBE data (9 May 1994 Contractor Report).

In April, SWA submitted a status report on "Beta-testing MSFC's data submission procedure with GLOBE data". The lessons learned in this effort included:

1) It took two weeks to install HDF on our SGI.

2) Using HDF requires the user to acquire specialized knowledge about its libraries and how to make calls to them. Anyone who wants to format their own data in HDF will need to take the time to learn the system.

3) The version of HDF that we installed only allowed arrays of floating point numbers to be stored. We wanted to store arrays of integers and strings, but we were unable to do that. More recent versions of HDF do allow more flexibility for types in array storage.

4) Currently, HDF only allows storage of one-dimensional arrays. We spent time attempting to store two-dimensional arrays before discovering that this could not be done.

5) We wanted to store multiple data file descriptions (because they might be created at different times), but HDF does not allow more than one file description. We then spent time experimenting with the strategy of appending text to the end of a currently existing data description, but we learned that HDF does not allow a user to do this either.

6) One of the major concerns of the GLOBE project is that researchers who download datasets might change them and then pass them on to other researchers as if they were in their original form. HDF does not provide a utility for verifying the data. We have developed a way to use a checksum to determine whether data in the current data set were changed.

7) The version of HDF that we installed did not provide any utilities for organizing tags and reference numbers.

As a consequence of focusing upon developing strategies for processing raw I and Q time series into calibrated LOS wind measurements, we began an investigation of expected surface returns. Our interest was not only in the strength of the surface return but also the Doppler effects of a moving surface. A model of lidar return from the ocean surface was developed and used to estimate wave motion affects on the DWL return. The conclusion was that any signal processing algorithm that relied on a "zero surface speed assumption" would be suspect. Blowing spray or foam and the vertical rise and fall of the waves combine to produce a bias in the lidar scanned surface motion (9 June 1994 Contractor Report).

A summary of additional activities carried out under this contract during 1994 are:

- continued evaluation of small-sat concepts for an EOS DWL mission;
- compiling a low level jet climatology to illustrate the value of a "PBL DWL" to the observation of moisture fluxes associated with boundary layer jets;
- evaluation of several signal processing schemes with specific interest in the sliding range gate approach; and
- making final revisions to the AMS Bulletin article that was accepted for publication (June 1995).

III. Papers and presentations funded totally or in part by this contract

The following were presented in **1990**:

Preliminary estimates of LAWS global observation opportunities below 15 km. GLOBE Meeting, March 7-8, Huntsville, AL.

Shot management for LAWS. LAWS Simulation Workshop, Goddard Space Flight Center, March, Greenbelt, MD.

Optimal sampling strategies for space-based laser wind sounders. Seminar at the Laboratoire de Météorologie Dynamique, Ecole Polytechnique, June, Plaiseau, France.

Optimal scanning pattern in partly cloudy regions. LAWS Science Team Meeting, August, Boulder, CO.

Role of OSSEs in the design of a space-based lidar wind sounder. Seminar at the European Center for Medium Range Weather Forecasts, September, Reading, England.

Optimal sampling strategies in partly cloudy regions for space-based laser wind sounders. Seminar at the Laboratoire de Météorologie Dynamique, Ecole Normal Supérieure, September, Paris, France.

Presentations funded under the LAWS contract in **1991** included:

LAWS, a career in global transports. Seminar given at Florida State University, January, Tallahassee, FL.

Clear line-of-sight (CLOS) statistics within cloudy regions and optimal sampling strategies for space-based lidars (G.D. Emmitt and G. Séze). *Proc. AMS Seventh Symp. on Meteor., Observa. and Instr.*, January, New Orleans, LA, 440-442.

An index of observation opportunities for EOS laser based instruments (G.D. Emmitt). *Proc. AMS Second Symp. Global Change Studies*, January, New Orleans, LA.

Optimal nadir scan angle for a space-based Doppler lidar wind sounder (G.D. Emmitt). *Proc. AMS Seventh Symp. on Meteor., Observa. and Instru.*, Special Session on Laser Atmospheric Studies, January, New Orleans, LA, J98-J99.

A reference atmosphere for LAWS trade studies: An update (S.A. Wood and G.D. Emmitt). *Proc. AMS Seventh Symp. on Meteor., Observa. and Instru.*, Special Session on Laser Atmospheric Studies, January, New Orleans, LA, J94-J97.

Simulating thin cirrus clouds in observing system simulation experiments (OSSE) for LAWS (G.D. Emmitt and S.A. Wood). *Proc. AMS Seventh Symp. on Meteor., Observa. and Instru.*, Special Session on Laser Atmospheric Studies, January, New Orleans, LA, 460-462.

Implications of several orbit inclinations for the impact of LAWS in global climate studies (R. Atlas and G.D. Emmitt). *Proc. AMS Second Symp. on Global Change Studies*, January, New Orleans, LA, 28-32.

Using a global spectral model in an observing system simulation experiment for LAWS - An EOS wind measuring system (T.N. Krishnamurti, J. Xue, G. Rohaly, D. Fitzjarrald, G.D. Emmitt, S. Houston and S.A. Wood). *Proc. AMS Second Symp. on Global Change Studies,*, January, New Orleans, LA, 23-27.

Presentations in **1992**:

Simulated LAWS performance profiles (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, July, Cape Cod, MA.

LAWS power budget simulations (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, July, Cape Cod, MA.

Review of mission science objectives for LAWS (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, July, Cape Cod, MA.

Presentations in **1993**:

Update on LAWS data simulations (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, January, Clearwater Beach, FL.

Design considerations for a Quick LAWS (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, January, Clearwater Beach, FL.

Update on ground-based lidar observations (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, January, Clearwater Beach, FL.

Simulation of space-based Doppler lidar wind measurements using ground-based single shot observations (G.D. Emmitt, J. Dieudonné, S.A. Wood and L. Wood). Paper presented at the *Optical Remote Sensing of the Atmosphere Sixth Topical Meeting*, March, Salt Lake City, UT.

Integration of LOWTRAN into global circulation models for observing system simulation experiments (S.A. Wood and G.D. Emmitt). Paper presented at the *Conf. Atmos. Transac. Models*, June, Boston, MA.

Using ground-based coherent Doppler lidars to evaluate algorithms for shot management and signal processing of proposed space-based wind sounders (G.D. Emmitt). Paper presented at the *Coherent Laser Radar: Applications and Technology Topical Meeting*, July, Paris, France.

System simulation studies in support of a technology and product demonstration mission for a space-based coherent Doppler lidar wind sounder (G.D. Emmitt). Paper presented at the *Coherent Laser Radar: Applications and Technology Topical Meeting*, July, Paris, France.

Presentations in **1994**:

Resolving ageostrophic winds with a space-based Doppler lidar wind sounder (G.D. Emmitt). Paper presented at the *Fifth Symp. Global Change Studies*, January, Nashville, TN.

Ocean wave motion effects on space-based airborne Doppler lidar wind sounders (G.D. Emmitt). Paper presented at the *Optical Soc. of Amer. Annual Meeting*, October, Dallas, TX.

The paper on which efforts began in 1994 was published in **1995**:

Lidar measured winds from space: An essential component for weather and climate prediction (WE Baker, G.D. Emmitt, P. Robertson, R.M. Atlas, J.E. Molinari, D.A. Bowdle, J. Paegle, R.M. Hardesty, R.T. Menzies, T.N. Krishnamurti, R.A. Brown, M.J. Post, J.R. Anderson, A.C. Lorenc, T.L. Miller and J. McElroy). *Bull. Amer. Meteor. Soc.*, 76, 869-888.

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